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Establishment Report: Permanent Plots to Monitor Douglas-fir Mortality Due to Western Spruce Budworm and Douglas-fir Beetle Interactions

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Introduction

Western spruce budworm (*Choristoneura occidentalis* Freeman) (WSBW), a native insect, is consistently the most widely distributed and destructive defoliator of coniferous forests in western North America. Found throughout the intermountain West, it is the most prevalent insect defoliator in Montana. Host tree species include Douglas-fir (*Pseudotsuga menziezii* [Mirb.] Franco), true firs (*Abies* spp.), spruce (principally *Picea engelmannii* Parry ex Engelm.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western larch (*Larix occidentalis* Nutt.), and rarely pines (*Pinus* spp.) (Fellin and Dewey, 1986).

WSBW outbreaks exhibit no particular pattern or trend in the West, although abnormally warm and dry weather may precipitate population outbreaks (Kemp and others, 1985). In the USDA Forest Service (USFS), Northern Region, the current outbreak has been building since 2001 (Bulaon and Sturdevant, 2006) (Fig. 1). In Montana alone 1,158,619 acres of visible defoliation were observed in 2006, up significantly from 453,739 acres mapped in 2005 (Gannon and others, 2007).

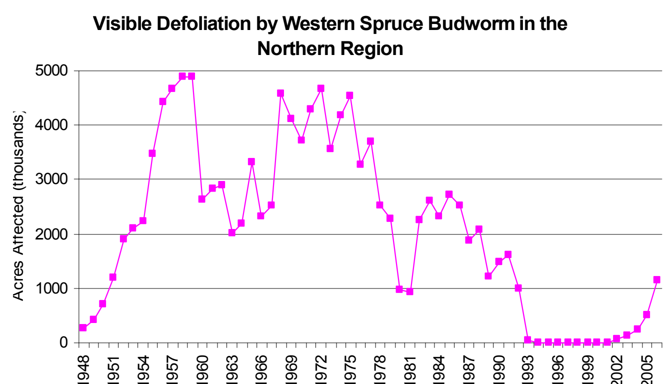

Figure 1. Annual visible defoliation by WSBW in the USFS Northern Region (R1) from 1948 to 2006 based on aerial detection surveys. Not all areas in Region are flown every year, adding minimally to the overall annual variation.

When severe, chronic outbreaks occur, damage may include top-kill, growth loss, and host mortality, especially regeneration failure. Trees weakened by defoliation also may be more susceptible to Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) (DFB), the most destructive bark beetle of Douglas-fir in North America. Whereas WSBW feeding can cause dramatic visual changes in a tree's appearance, more Douglas-fir mortality in Montana is attributable to DFB.

Recent observations in heavily defoliated stands on the Helena National Forest, suggest there may be a relationship between heavy defoliation by WSBW (>90% total crown) and subsequent attack by DFB (Sturdevant and Kegley, 2006). Validity of this relationship has not been tested in the Northern Region. The importance of consecutive years of defoliation also is unknown. Our establishment of permanent plots in several areas of current WSBW-caused defoliation will allow us to monitor Douglas-fir mortality caused by defoliation and/or bark beetle attack. We may also be able to determine defoliation characteristics most attractive to DFB.

Methods

Three locations with high current WSBW defoliation were identified using 2005-2007 aerial detection survey (ADS) maps and ground assessments (Fig. 2). Because ADS identifies defoliation only when significant enough to become apparent from the air, defoliation not visible in the lower canopy might be missed. In addition, other defoliators or diseases might create similar crown thinning. Thus, actual presence and intensity of WSBW activity was confirmed from the ground. All locations chosen have a history of both WSBW and DFB activity.

Within each of these locations, we chose three sites (stands), one to three miles apart. Stands were predominantly Douglas-fir with breast-height diameters (dbh) of eight inches or greater. Although we did not examine individual trees for existence of root disease, stands were to have little to no apparent root disease affects (i.e. no visible mortality centers nor thinning crowns not due to defoliation).

At each site we established 10 variable-radius plots using a basal area factor of 20. Distance between plots was at least three chains (~200 feet). However, if the plot at three chains did not contain more than seven Douglas-fir trees greater than 8 inches dbh, the distance was increased another chain. If no appropriate stand was located within seven chains we continued the transect in a more promising direction.

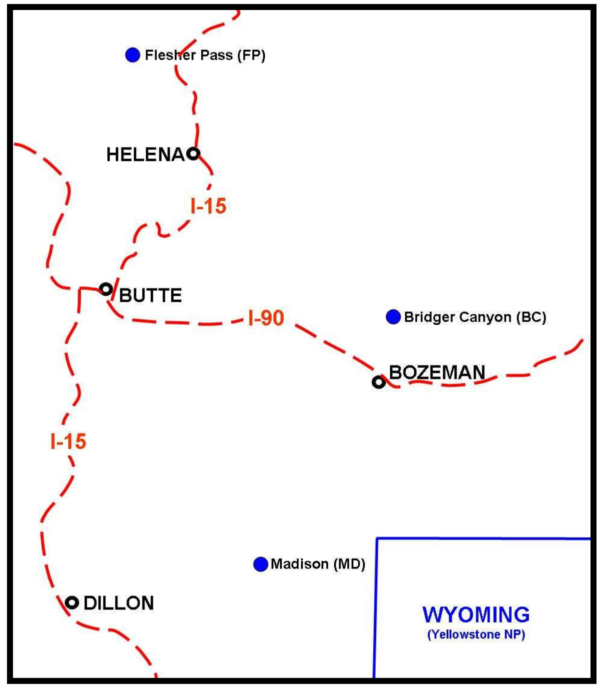

Figure 2. General position of the three locations of study plots.

Plot center was staked, a GPS coordinate was recorded, and numbered tags were nailed at dbh to in-plot trees. Data recorded for each tree included tag number, tree species, dbh (±1 inch using Biltmore sticks), canopy position (dominant, intermediate, understory, open grown), overall crown defoliation (<25%, 26-75%, >75%), defoliation of current year growth (<50%, >50%), WSBW-caused mortality (very few green needles remaining and no bark beetle frass apparent), and bark beetle activity (current, last year, or older successful DFB attack, strip or unsuccessful attack, or attacks by secondary beetles).

Data gathered on the 10 plots at each site was entered into the FINDITS program to obtain summaries of stand conditions. Details on this program and its calculations made can be found in Bentz (2000). Note that we changed

defoliation levels represented by FINDITS defoliation codes 12 & 13. Current growth defoliation was represented by 'User Codes' 31 and 32.

Results: Stand Condition Summaries

Summary data on whole-tree and new-growth defoliation are shown in Figures 3 and 4, respectively. Results indicate that levels of heavy (>75%), whole-tree defoliation were significantly different among the three sites [*P*-value = 0.014, multiple response permutation procedure (MRPP) analyses (Petrondas and Gabriel, 1983). Simultaneous multiple comparisons to differentiate plot areas could not be conducted with so few replications.]. Flesher Pass (FP) (Helena NF) displayed the greatest levels of heavy defoliation, followed by Bridger Canyon (BC) (Gallatin NF) and Madison (MD) (Beaverhead NF). Data on defoliation of new growth confirms that most trees at FP were under current high defoliation (>50%) (or dead), resulting in fewer lightly defoliated trees. However, light defoliation of new growth was not significantly different at the 3 sites ($P>0.05$) using MRPP).

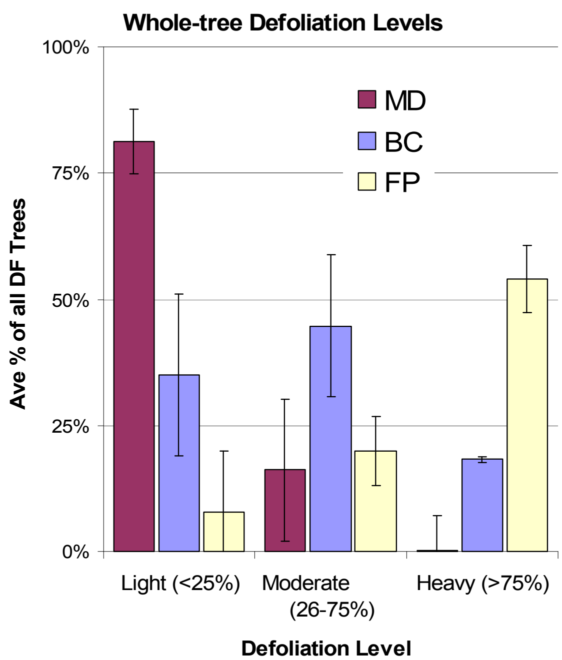

Figure 3. Average percentage of Douglas-fir trees at each of three whole-tree defoliation levels. Error bars are 95% confidence intervals. (MD=Madison, BC=Bridger Canyon, FP=Flesher Pass)

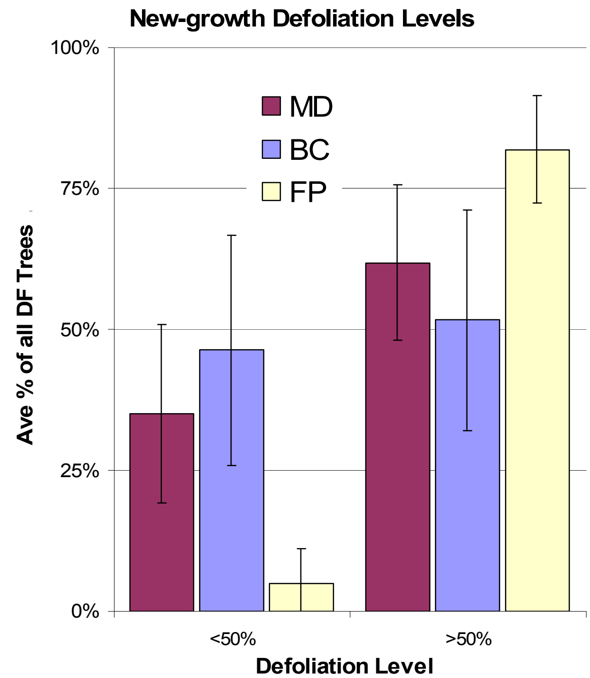

Figure 4. Average percentage of Douglas-fir trees in two new-growth defoliation levels. Error bars are 95% confidence intervals. (MD=Madison, BC=Bridger Canyon, FP=Flesher Pass)

Stand summary data indicates FP sites are unique in having more DF per acre as mortality (55 average [range 29-105] versus 3 and 2 [range 0-6] for BC and MD). Mortality due to defoliation alone was highest at FP, although constituted the largest proportion of total mortality at BC (23 and 4 average DF per acre, respectively). No defoliation-caused mortality was recorded at MD. Similarly, mortality due to current (2007) and last year (2006) DFB activity was only present at FP (16 and 5 DF per acre, respectively), although older DFB-caused mortality was present at both FP and MD (2 DF per acre each). Although BC has a history of DFB activity, it was interesting to note that none was detected in our survey despite the many years of defoliation.

At MD there are fewer total (live and dead) DF trees per acre than at BC or FP (94, 156, 166, respectively). Yet, due to the larger QMD of those trees (18.5, 16, 15.1, respectively) the average DF basal areas are fairly similar (157, 179, 179, respectively). Meanwhile, MD sites may be unique in having visible root disease effects on crown condition, although this was the only location where a root disease specialist was present with the crews.

Only BC3 had additional WSBW host tree species (SAF and ES). Although defoliation was measured on these trees, no DFB activity would be expected. Lodgepole pine also was present on five of nine sites. However, trees per acre and basal areas of this species were low with only MD3 containing any significant numbers. A more detailed summary of individual site conditions is provided in Table 1.

Discussion

We expected that levels of whole-tree defoliation would reflect defoliation history with heavier defoliation in stands experiencing more consecutive years of WSBW activity. However, aerial detection survey (ADS) data from 1999 to 2007 does not support this assumption. (See Table 2.)

According to ADS maps all FP sites have been subject to three years of WSBW activity and possibly up to five years. However, BC stands have experienced defoliation longer with seven years of WSBW activity, often at high levels. Meanwhile, MD defoliation has been fairly recent, recorded in one stand in 2006, with levels high in all three stands starting only in 2007. Based on ADS data we would expect higher whole-tree defoliation levels at BC, followed by FP and MD.

We are not sure why whole-tree defoliation levels do not reflect the duration of the defoliation event. Differences in defoliation-level assessment due to point of view (ground versus aerial) or use of such a broad category for heavy defoliation (50-99%) may be factors.

New-growth defoliation was >50% on more than half the live DF trees, reflective of 2007 ADS survey results mapping all sites as highly defoliated.

Both defoliation intensity (whole-tree defoliation) and longevity (years of defoliation) may affect DF survival. Although no conclusions can currently be made with our limited data (three sites at one year), DF mortality levels are better reflected by defoliation intensity than longevity.

Absence of current DFB-caused mortality on BC and MD does not necessarily indicate that trees are unsuitable for DFB colonization. In order for DFB-caused tree mortality to occur, DFB needs to be present and active in the area.

Using ADS maps, we identified the nearest DFB-caused mortality detected during the 2005, 2006, and 2007 surveys. (See Table 3.) Although BC had high levels of defoliation and a longer history of WSBW activity than FP, DFB activity has been further than one mile from the plots during all three years. At the other extreme, DFB activity has been less than four miles distant from MD plots during all three years, often with distances less than a half-mile. Without ground checks it is not possible to know if this DFB activity at MD is occurring in more heavily defoliated stands than those we measured or if our stands have just been missed to date.

Although all FP plots contained some level of DFB activity in both 2006 and 2007, ADS surveys were not able to discern the mortality. In all three years mapped activity was over two miles from sites. However, it is possible that heavy defoliation masked DFB activity. From the air, a red-crown is the primary signature of DFB-caused mortality. If few needles remain, this signature would be absent.

All plots will be revisited in summer 2008 to assess WSBW-caused defoliation levels and bark beetle activity. Continued monitoring beyond 2008 is planned although visits will be based on presence of WSBW defoliation. Ultimately, individual tree mortality will be assessed to determine which tree and stand characteristics best predict tree death. However, to determine if defoliation levels influence DFB’s selection of host trees bark beetle populations must increase within the study areas shortly after defoliation. To increase our likelihood of capturing additional data on DFB activity in defoliated stands, we may establish additional plots at other locations in subsequent years.

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Table 1. Western spruce budworm (defoliator) and Douglas-fir beetle (DFB) activity, as well as basic stand characteristics for the three sites at each of the three locations: Bridger Canyon (BC), Madison (MD), and Flesher Pass (FP). Data summary is from FINDITS (Bentz, 2000) and is given as trees-per-acre unless otherwise specified. All Douglas-fir trees (DF) over 5" in diameter at breast height (live and recently dead) were used in calculations unless otherwise specified.

	BC1	BC2	BC3*	MD1	MD2	MD3	FP1	FP2	FP3
DEFOLIATION LEVELS of DF:									
All foliage (whole-tree):									
Light Defoliation (<25%)	38.4	43.6	78.7	89.7	72.6	64.2	0.6	40.6	4.7
Moderate Defoliation (26-75%)	48.1	93.5	71.4	21.1	2.1	25.5	25.9	40.9	26.7
Heavy Defoliation (>75%)	36.9	48.2		0.9			51.3	101.6	119.1
Current year foliage (new-growth):									
Defoliation <50%	78.9	51.9	74.4	32.8	38.5	23.8		22.2	7.1
Defoliation >50%	44.5	133.4	75.8	79.0	36.1	64.0	90.7	166.6	143.3
Defoliation Mortality:	2.2	5.7					17.6	15.7	35.8
BARK BEETLE ACTIVITY on DF:									
Current 2007 DFB attack							9.1	10.4	59.7
2006 DFB attack							3.3	1.9	9.4
Older DFB attack				1.4	0.8	3.8	1.5		
Unsuccessful DFB attack							0.6	0.6	14.2
Current DFB strip attack								2.6	6.3
Current secondary beetle attack								1.1	8.3
OTHER on DF:									
Undamaged Stand			2.2						
Unknown Mortality			2.2			0.9			
Root Rot affected (live)					1.3	4.6			
STAND CHARACTERISTICS:									
Trees per acre of DF (live)	123.4	185.3	152.3	111.7	74.7	89.7	69.3	172.6	90.7
Trees per acre DF (dead)	2.2	5.7	0	1.4	.8	4.7	31.5	29.2	105.0
%of stand is DF (trees/acre)	98.9	100	78.4	100	94.9	74.7	100	100	98.2
DF QMD (live and dead)	17.9	14.7	15.4	19.0	19.3	17.0	18.4	13.5	13.5
Basal area of DF (live)	196	192	146	184	140	126	126	146	94
Basal area of all species (live)	198	192	168	184	144	136	126	146	96
Other tree species (live tree/acre; live basal area)	LPP (1.4, 2)		SAF (22,6) ES (15,10) LPP (6,6)		LPP (4, 4)	LPP (30,10)			LPP (1.6, 2)

*BC3 also contained the western spruce budworm host trees of subalpine fir (SAF) and Engelmann spruce (ES). High, medium and low whole-tree defoliation levels on these additional hosts were 0, 4.5, 16.5 and 0, 3.0, 3.0 trees per acre for SAF and ES, respectively. New-growth defoliation levels were 0, 21.1 and 0, 6.0 trees per acre of <50% and >50% for SAF and ES, respectively. Lodgepole pine (LPP) is not typically a host species so defoliation was not recorded on it.

Table 2. Total acres affected by WSBW as detected by aerial detection survey for the reporting area in which sites are located, and level of WSBW activity at each site. Site defoliation levels are given as low (L) or high (H), corresponding to <50% or >50% visible crown defoliated, respectively. (BC=Bridger Canyon, MD=Madison, FP=Flesher Pass)

Aerial Detection Survey Summary of Sites - WSBW

	Gallatin*	BC1	BC2	BC3	Beaverhead*	MD1	MD2	MD3	Helena*	FP1	FP2	FP3
1999	0	0	0	0					0 **	0	0	0
2000	0	0	0	0	0 **	0	0	0	412	0	0	0
2001	0	0	0	0					1,309	0	0	0
2002	19,934	**H**	**H**	**L**	23,500	0	0	0	4,567	0	0	0
2003	56,004	**H**	**H**	**L**	15,224	0	0	0	29,653	0	0	**H**
2004	73,009	**H**	**H**	**L**	36,801	0	0		31,173			
2005	124,487	**H**	**H**	**L**	60,818	0	0	0	145,039	**H**	**H**	**L**
2006	208,787	**H**	**H**	**H**	150,194	0	0	**L**	413,384	**L**	**L**	**L**
2007	*n/a*	**H**	**H**	**H**	*n/a*	**H**	**H**	**H**	*n/a*	**H**	**H**	**H**

* Reporting area includes all ownerships within the National Forest boundary.

** Acres affected estimates are determined from ADS polygons and may be subject to errors.

Blank cells indicate specified area was not flown.

Table 3. Estimated distances (in miles) of plots from nearest Douglas-fir beetle (DFB) activity detected during aerial detection surveys (ADS) in 2005, 2006, and 2007. (BC=Bridger Canyon, MD=Madison, FP=Flesher Pass)

Aerial Detection Survey Summary of Sites – DFB*

	Gallatin			Beaverhead			Helena		
	BC1	BC2	BC3	MD1	MD2	MD3	FP1	FP2	FP3
2005	2-3	1-2	3-4	<0.5	0.5-1	<0.5	2-3	2-3	>3
2006	>10	>10	>10	3-4	0.5-1	2-3	>3	>3	2-3
2007	8-9	9-10	>10	1-2	<0.5	<0.5	>4	>4	>3

*ADS maps fading trees indicative of DFB activity that occurred the previous year.